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AUTHOR Capps, Joan; Schueler, Paul
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ABSTRACT

At Raritan Valley Community College (RVCC) in New Jersey, an honors philosophy course was developed which taught mathematics and science concepts independent of computational skill. The course required that students complete a weekly writing assignment designed as a continuous refinement of logical reasoning development. This refinement was facilitated by peer-written responses to the essays by each member of the class. Readings for the class, including T. S. Kuhn's "The Structure of Scientific Revolutions" and J. W. Knedler, Jr.'s "Masterworks of Science," facilitated an examination of the art form present in high-order scientific thought as evidenced in a sample of original works by Newton, Einstein, Galileo, and other prominent scientists. Topics addressed in the course included the following: (1) the contributions of the ancients to scientific and mathematical thought; (2) the concept that mathematical truth can be called time-dependent; (3) Plato's conviction that the study of mathematics is essential in the cultivation of philosophers; (4) Aristotle's contributions as the systematizer of deductive logic and as a writer on physical subjects; (5) Euclid's "Elements" as the "Bible of Mathematics"; (6) ideas of space under Euclidean, non-Euclidean, and relativistic theory; (7) inductive reasoning as a necessary component of the thought processes used by mathematicians; (8) Leibniz's and Newton's contributions to calculus; (9) the computer revolution of the 20th century; (10) theories of light, electricity, geocentricity, and relativity; and (11) chemistry, alchemy, biology, physics, and DNA. The underlying premise of the course was that logical principles and analogical reasoning, regulated by doubt and the scientific method of formulation and testing of hypotheses, broadened students' knowledge and understanding of science. (JMC)

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"Understanding Scientific Ideas", an Honors Course

Joan Capps and Paul Schueler
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(Acknowledgment: The authors would like to thank Jere Jones for his encouragement and guidance in the writing of this paper, just as he guided students in developing their ability to think critically.)

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The question, "Is it possible to teach mathematics/science concepts independent of computational skill?" receives an affirmative answer in the Honors course, UNDERSTANDING SCIENTIFIC IDEAS. This philosophy course embodies two unique educational principle:

- interdisciplinary faculty and student approach;
- mathematical and scientific understanding is learning to manipulate rules whereas conceptual understanding is learning that they are the rules.

Wittgenstein's concept of a "language game" is a social activity making use of language for the purpose of understanding and clarification. The fact that language or discussion in which reasoning is employed must take place before mathematical/scientific reasoning is possible changed the "star performer" role of the instructor to that of an "orchestra leader" with dialogue among the faculty and student "players" augmented by a major cooperative student-writing "performance" designed to foster a conceptual understanding of the art-form called scientific thinking with peer written give-and-take.

The unique student weekly writing assignment was a continuous refinement of logical reasoning development on "Elegance and Beauty of Scientific Thought." This refinement was facilitated by peer-written responses to each edition of the essay by each member of the class.

While the discussion of mathematics, physics, chemistry, and biology preceded, students were developing their ideas based on their responses to each other and the influx of scientific ideas discussed in the classroom. Early essays often referred to Euclid or Archimedes; later in the semester, Galileo or Newton might be mentioned. Students also drew on their own experience; one used the beauty of a dancer as an analogy, another the elegance of a computer program.

The degree of growth shown in the weekly essays varied from student to student: some were never able to get beyond wallowing in details while others went through weeks in which they appeared to lapse into a kind of confused despair. Some, however, made great progress in reaching an understanding of the role that language and meaning play in shaping these abstract scientific concepts. Significantly,the student who, by our consensus, developed her ideas to the greatest extent over the semester was not only not a science major, but was enrolled in a developmentalmathematics course who had to have "special permission" to register for the Honors course.

The essay-exchange system was implemented by a matrix which

was controlled by Professor Jere Jones of the Philosophy Department at Raritan Valley Community College who was the program director of this team-taught course. He provided the leadership for a systematic examination of the quest for aesthetic perfection in scientific thought as demonstrated in the original work of the masters in the history of science. Reference to the remarkable principle of discovery and advancement in scientific thought, namely,the constructive doubting of a traditional belief was a theme that continuously surfaced. Joan Capps of the Mathematics Department and Paul Schueler of the Chemistry Department provided the scientific content that attempted to keep the reasoning from becoming "empty", to paraphrase Kant. Thus, the language and meaning of the abstract concepts were continually being "glued" together by Prof.Jones to develop the process of scientific conceptualization rather than just learning the facts that the scientist and mathematician were proudly explaining.

The readings revealed a rich heritage of scientific thought and the students discovered the creativity, courage, and uniqueness of genius-level thought-processes. The class became aware of the frame of reference and the existence of technical and the sociological factors from which the scientific theories evolved via the philosophical "glue" continuously melding the scientific ideas into one holistic unit.

Students read THE STRUCTURE OF SCIENTIFIC REVOLUTIONS by T.

S Kuhn to understand what constitutes the art form that is present in high-order scientific thought. The lectures were augmented with original readings from the MASTERWORKS OF SCIENCE edited by John Warren Knedler, Jr. They included the sections from Volume I: ELEMENTS by Euclid, ON FLOATING BODIES AND OTHER PROPOSITIONS by Archimedes, ON THE REVOLUTIONS OF THE HEAVENLY SPHERES by Copernicus, PRINCIPIA by Newton; RELATIVITY: THE SPECIAL AND GENERAL THEORY by Einstein; the sections from Volume II: DIALOGUES CONCERNING TWO NEW SCIENCES by Galileo, THE ATOMIC THEORY by Dalton, EXPERIMENTAL RESEARCHES IN ELECTRICITY by Faraday, THE PERIODIC LAW by Mendeleyev; and one section in Volume III: THE ORIGIN OF THE SPECIES by Darwin. The readings provided the scientific language used in this art form - although they often did not understand completely the detailed mathematical language in which the scientific concepts were expressed in. They soon learned that details were not as important as the relation of the ideas to previously held ideas and to the logical structure of scientific thought.

The "Great Moments in Mathematics" approach of Howard Eves was used to describe the contributions that the ancient Egyptians, Greeks, Babylonians, Hindus, Arabs, and Chinese made to scientific and mathematical thought before Thales' work on demonstrative geometry in 600 B.C. The Pythagorean philosophy that the whole number is the cause of various qualities of man and matter was examined. This led to an examination of number properties and arithmetic in relation to geometry, astronomy, and

music - which were the liberal arts of the Pythagorean fraternity.

The concept that mathematical truth can be called time-dependent was presented when Zeno's paradoxes of motion of 450 B.C., were discussed. These paradoxes assert that motion is impossible whether we assume a magnitude to be infinitely divisible or made up of a large number of atomic parts. Whatever might have been the intended motive of the paradoxes, their effect was to exclude infinitesimals from Greek demonstrative geometry. The fact that Georg Cantor, the inventor of set theory and the theory of the infinite, continued with the arguments of these paradoxes as late as 1874 demonstrated the influence of medieval theology and its intricate arguments on the continuous and the infinite in scientific thinking.

Plato's conviction that the study of mathematics is essential in the cultivation of philosophers and those who should govern his ideal state was emphasized. The Method of Exhaustion of his pupil, Eudoxus, was detailed as an example of the Platonic School's answer to the paradoxes of Zeno in 370 B.C. The fact that his "reductio ad absurdeum process" in the squaring of the circle problem assumes the infinite divisibility of magnitudes and thus can be considered to be one of the first problems occurring in the history of the calculus demonstrated the truth of Newton's statement that if he had seen farther than other men, it was only because he had "stood on the shoulders of giants."

Aristotle's ideas were continuously cited as part of the unifying "thought-glue", since, although not a professed mathematician, his contribution as the systematizer of deductive logic and writer on physical subjects shows an unusual grasp of the mathematical method. His law of the excluded middle was presented as was the Aristotelian theory of motion that required that all motion other than the "natural" motions (the circular motion of the spheres, or the downward motion of objects toward the earth) requires a mover. The latter showed Aristotle anticipating Newton's First Law of Motion by two thousand years and then rejecting it and "proving" the impossibility of a vacuum by logical argument based on his initial postulates. Class discussion centered around the shaping of Aristotle's world view by the social and cultural patterns of Hellenic thought. thinking critical can occur in context, embedded in the culture of the thinker. The students were constantly challenged to consider scientific ideas not only from our late twentieth century perspective, but also from the viewpoint of the original thinkers.

Euclid's ELEMENTS was presented to the class as the "Bible of Mathematics" that organized much of the thought of mathematics and science as a series of theorems, postulates, and proofs through the years 300 B.C. This formal postulational thinking process, that has penetrated into every field of mathematics and thus science, was explained with the distinctions between an axiom and a postulate of the early Greek

mathematicians and philosophers presented. It was emphasized that Euclid adhered to the formal concept that an axiom is an assumption common to all sciences whereas a postulate is an assumption peculiar to the particular science being studied. The fact that modern mathematics makes no distinction between axioms and postulates was discussed.

Euclid's parallel postulate was developed in detail to emphasize the fact that attempts to derive this postulate as a theorem from the nine "axioms" and "postulates" occupied geometers for over two thousand years and culminated in some of the most far-reaching developments of modern mathematics. Some historical proofs were presented to show that sooner or later they rested upon a tacit assumption that was equivalent to the postulate itself.

The impossibility fo solving the three famous problems of antiquity with the Euclidean tools (straight-edge and compass) was shown in the 19th century. It was pointed out that theory of equations or algebraic theory is necessary to solve the quadrature problem, the duplication of the square, and the trisection of the angle to demonstrate the effect of the changing notations or symbolism on mathematical truth.

Ideas of space were explored under Euclidean, non-Euclidean, and relativistic theory. Descartes and Fermat's work with analytic geometry was demonstrated to show how the task of

proving a theorem is cleverly shifted to that of the establishment of a correspondence between points in a plane and ordered pairs of real numbers thereby making possible a correspondence between the points in the plane and algebraic equations in two-variables.

It was pointed out that, although the logic of mathematics employs deductive reasoning, the process of inductive reasoning present in the scientific method is a necessary part of the thought processes used by mathematicians in making their discoveries. Emphasis was placed on the fact that challenging an axiom was the method by which Einstein came to invent the theory of relativity; Lobachevsky and Bolyai challenged Euclid's axiom of parallels to develop non-Euclidean geometries that are used in physics; Hamilton and Cayley challenged the axiom that multiplication is commutative to develop matrix theory; Lukasiewicz and Post challenged Aristotle's axiom of the excluded middle in their m-valued logic. Thus, the mathematics presentations were guided by the truth of Georg Cantor's famous aphorism: "The essence of mathematics lies in its freedom."

Leibniz and Newton's contributions to Calculus were contrasted with basic similarities and differences mentioned. The fact that Newton resolved problems of infinitesimals, limits, and summations by referring to the motion of FLUXIONS and Leibniz's search was motivated by his plans for a theory of mathematical logic and symbolic method with formal rules that

would obviate the necessity of thinking was discussed. The convenience and flexibility of Leibniz's use of the integral sign as the elongated S and his use of dx as an arbitrary finite interval with his elementary rules for differentiation that are retained as the symbolism of Calculus was contrasted with fluxional notation of Newton.

The computer revolution of the twentieth century with its Systems Theory was discussed with the question of whether numerical statistics is making the old view of the tree of mathematics obsolete. Students initiated a discussion of our twentieth-century computer-oriented society with numerical approaches to theory and questioned a calculus tree trunk to the elimination of potential mathematicians who might prefer non-calculus fields.

Excerpts from Archimedes "On Floating Bodies" reveal both the power and the limitations of the Euclidean methods of deductive reasoning and geometric construction, when applied to physical science. "The Sand Reckoner" provides fascinating insights into the sophisticated heliocentric theories (particularly those of Aristarchus) which coexisted with Aristotelian geocentrism.

Geocentric theory culminated in Ptolemy's astronomical and cosmological system of epicycles, which was so successful in reconciling celestial motion that it can still be used for

navigation. By Copernicus' time, nearly 1400 years later, astronomical technology had hardly changed, but attitudes and assumptions had. The focus of the discussion was to understand why heliocentrism gradually replaced Ptolemy in spite its initial inferiority in practical navigation and celestial prediction.

As perhaps the first great observational scientist (and certainly its first great publicizer), Galileo stands as a bridge between ancient and modern science. Students reading from his "Dialogues" were able to hear echoes of Plato and Euclid, with a new emphasis on observation and experiment.

Newton's "Principia" established the mechanical world view that dominated science for the next two centuries. The class discussed Newton's Laws in non-technical terms, seeing qualitatively how the vast edifice of Newtonian physics is constructed from these simple but revolutionary postulates.

An introduction to the theories of light an electricity stimulated a lively student response. The class was quick to appreciate that efforts to "mechanize" particularly through a postulated mechanical "ether", were doomed to failure which lead to Einstein's theories of special and general relativity, and to quantum mechanics in the early twentieth century. (In keeping with the interdisciplinary and collaborative nature of the course, we employed a "guest lecturer", Professor Darryl Walke, to lead the class discussions of relativity. His contribution is

gratefully acknowledged.)

Although the discussion of special and general relativity were kept at a descriptive, non-mathematical level, the students were able to appreciate that Einstein's ability to examine the critical state of Newtonian mechanics in the early twentieth century (of which many his contemporaries were well aware) led him to formulate a new theory which was a breathtaking departure from Newtonian thought.

The class began its examination of the development the ideas of chemistry where we began before, in the Classical world of ancient Greece. Although practical chemistry (metallurgy, pottery, glassmaking, dyes, embalming, tanning, brewing, for example) was pursued by artisans, "theoretical" chemistry is traced to the Ionians (with importations from India), culminating in the competing theories of Plato and Democritus. The class discussed the contrasts between the idealistic, continuistic Platonic system and the materialistic atomic theory of Democritus; students saw how these contrasts were not just scientific, but encompassed social and political differences as well. The Platonic/Aristotelian system carried the day, but not for any compelling "scientific" reasons--there was no experimental evidence supporting or refuting either theory.(Bernal, 1971)

Alchemy, first identified with Plotinus (ca 270), was a

descendant of that system; students could hear the echoes of Platonic "ideals" in the alchemists quests for gold. That blind alley occupied chemistry for more than one thousand years (Newton himself, the creator of modern physics, was a fervent alchemist as well).

The students were introduced to the revolutions in chemistry brought about in the seventeenth century through the study of gases by such as Torricelli (a student of Galileo) and Boyle (a contemporary of Newton in the Royal Society.) They saw that although Newton was an atomist, his mechanical, materialistic world-view did not dominate chemistry as it did physics. The class discussed the survival of Platonic/alchemical ideas in the phlogiston theory of the eighteenth century.

The class examined the beginnings of modern chemistry largely through the work of Lavoisier (who systematized nomenclature and formulated empirical laws) and Dalton (who finally revived atomism in a theory firmly rooted in experimental data.) The second half of the century saw the empirical discovery of the Periodic Table, and the beginning of an understanding of the three-dimensional structure of molecules--atoms were finally becoming accepted as real entities.

The early twentieth century saw a revolution in chemistry comparable to relatively in physics. Much as the crisis caused by the failure of the mechanical ether paved the way for

Einstein, the failure of the statistical mechanics to account for black-body radiation (the "ultraviolet catastrophe") contributed to the development of quantum mechanics. The class grappled with one of the most powerful, as well as intuitively incomprehensible theories of modern science. Finally, the structure of the atom and its chemical behavior were placed on firm theoretical ground, but at the price of being even less accessible to the non-expert.

We were once again fortunate to employ a guest, Professor Roger Johnson, to lead the discussion of biology. He focused of the two major ideas unifying biology: cell theory and evolution. Our students were much more familiar and at ease with central themes of biology than of mathematics, chemistry, or physics. As a result, less class time was spent on a description of the language and the rules, and more on the development of the ideas, from Lamarck to Darwin and Wallace, to the Neo-Darwinism of this century, and to the present, in which we seem to be right in the middle of a scientific revolution. Molecular biology, biochemistry, and biophysics are converging on a synthesis in which the genetic machinery of the cell is the key to a new understanding of physiology, behavior, and evolution.

Tching session on the topic of DNA. Each member of the class gave a presentation to demonstrate his/her ability to develop a coherent account of some scientific aspect of this theory. It is interesting to note that the level of science or mathematics course training did affect a student's ability to

manipulate details but did not appear to affect his/her conceptual understanding of the logic of scientific thought processes.

Although taught only once, we do contend that since three out of eight students transferred to research universities after taking the course and two of the other students took additional science courses when they did NOT intend to, the course was successful in: developing more confidence with science; diminishing the fear factor always present in math/science courses; understanding the relation and necessity of learning the language of science (mathematics) and a conceptual understanding of that part of science itself. One of the students has entered the Microbiology Honors program at North Carolina University with the course being accepted for transfer Honors credit.

As science and mathematics instructors, who have always been concerned with rigorous developments of fact, we were surprised to see the level of scientific understanding that is gained when emphasis is placed on critically analyzing the process of science with an application of the difficulties which scientists encounter to understand natural phenomena.

Since philosophy demands a reverence for integrity in its concern for significance, all instructors agree that this approach to thinking critically - one that entails logical principles and analogical reasoning regulated by the method of

doubt in addition to the scientific method of formulation and testing of hypotheses - develops an understanding of the perspectives of others and thereby broadens the student's knowledge and understanding of science. Next time we teach the course, we will consider expanding the time to two-semester or cutting down on the number of scientists read to enable the students to explore the most important scientific concepts in greater depth.

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